REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*
23/06/2014

2. REPORT TYPE
Final Technical Report

3. DATES COVERED *(From - To)*
Oct 2010 - Dec 2011

4. TITLE AND SUBTITLE
Final Technical Report: Optical Data Transmission in a Turbid Environment

5a. CONTRACT NUMBER

5b. GRANT NUMBER
N00014-11-1-0202

5c. PROGRAM ELEMENT NUMBER

5d. PROJECT NUMBER
130202SP

5e. TASK NUMBER

5f. WORK UNIT NUMBER

6. AUTHOR(S)
Farr, Norman E.; Boss, Emmanuel S.; Hill, Paul S.; Law, Brent A.; Milligan, Timothy G.; Trowbridge, John H.; Sherwood, Christopher R.

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Woods Hole Oceanographic Institution
266 Woods Hole Road
Woods Hole, MA 02543-1501

8. PERFORMING ORGANIZATION REPORT NUMBER
15309.00

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Office of Naval Research
875 North Randolph Street
Arlington, VA 22203-1995

10. SPONSOR/MONITOR'S ACRONYM(S)
ONR 322

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
DISTRIBUTION STATEMENT A: Distribution approved for public release; distribution is unlimited.

13. SUPPLEMENTARY NOTES

14. ABSTRACT
The goal of the proposed work is to measure the effects of varying amounts of suspended particulate near the seafloor on data transmission with a free space, omni-directional, optical link and to test the viability of communicating through the air-sea interface. An optical channel measurement will be performed where received power levels, bit error rate statistics, and raw data “snapshots” will be collected for several transmission rates. A transmissometer will be installed with the equipment to provide real-time water quality information. The proposed work will demonstrate the performance of a free-space optical telemetry system in shallow water in changing optical conditions.

15. SUBJECT TERMS
Communications, Ocean Optics, Optics

16. SECURITY CLASSIFICATION OF: a. REPORT	b. ABSTRACT	c. THIS PAGE	17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
					Norman E. Farr
					19b. TELEPHONE NUMBER *(Include area code)*
U	U	U	UU		508/289-3499

Final Technical Report: Optical Data Transmission in a Turbid Environment

Award Number: N00014-10-1-0202

Norman E. Farr
Department of Applied Ocean Physics and Engineering
Woods Hole Oceanographic Institution
266 Woods Hole Road, MS# 18
Woods Hole, Massachusetts 02543
Phone: (508) 289-3499 – Fax: (508) 457-2154 – E-mail: nfarr@whoi.edu

In collaboration with:

Emmanuel S. Boss
School of Marine Sciences
5706 Aubert Hall
University Of Maine
Orono, Maine, USA 04469-5706
Phone: (207) 581-4378 – Fax: (207) 581-4388 – E-mail: emmanuel.boss@maine.edu

Paul S. Hill
Department of Oceanography
Dalhousie University
P.O. Box 15000
Halifax, Nova Scotia, CANADA B3H 4R2
Phone: (902) 494-2266 – Fax: (902) 494-3877 – E-mail: paul.hill@dal.ca

Brent A. Law and Timothy G. Milligan
Fisheries & Oceans Canada
Bedford Institute of Oceanography
P.O. Box 1006
Dartmouth, Nova Scotia, CANADA B2Y 4A2
Phone: (902) 426-3273 – Fax: (902) 426-6695 – E-mail: milligant@mar.dfo-mpo.gc.ca

John H. Trowbridge
Woods Hole Oceanographic Institution
266 Woods Hole Road, MS# 12
Woods Hole, Massachusetts 02543
Phone: (508) 289-2296 – Fax: (508) 457-2194 – E-mail: jtrowbridge@whoi.edu

Christopher R. Sherwood
U.S. Geological Survey
384 Woods Hole Road
Woods Hole, Massachusetts 02543-1598
Phone: (508) 457-2269 – Fax: (508) 457-2310 – E-mail: csherwood@usgs.gov

LONG-TERM GOALS

The goal of this research is to measure the effects of varying amounts of suspended particulate near the seafloor on data transmission with a free space, omni-directional, optical link and to test the viability of communicating through the air-sea interface. A better understanding of turbulence and turbidity and their influence on the optical channel is critical to the development of optical communications in coastal waters.

OBJECTIVES

1. Deploy an optical telemetry system in a location where optical properties are measured by our collaborators.
2. Demonstrate optical telemetry through the air-sea interface.
3. Identify relationships between optical link performance and observed optical water properties

APPROACH

The approach is to use existing optical communications equipment and deploy it in shallow water at a location where optical and acoustic water proprieties are being studied by other investigators. Our optical communications testing to date has been limited to overnight tests with a single transmissometer measurement. Our collaborators will provide measurement of nine wavelengths of absorption and attenuation, multiple backscatter, CDOM fluorometer, and several other parameters. We will measure optical link performance and received power for two wavelengths of light. Dr. Boss will compute underwater visibility, which we will then use to model the light field produced by the optical modem. Collaborating with Drs. Hill, Sherwood, and Trowbridge, our data will be used to develop and constrain a sediment concentration module that will be incorporated into the Community Sediment Transport Modeling System (CSTMS).

WORK COMPLETED

In September and October 2011, two optical telemetry systems were deployed at the Martha's Vineyard Coastal Observatory (MVCO) 12m Node and Air-Sea Interaction Tower (ASIT). The 12m Node system consists of tripods equipped with optical receivers and emitters located at 1 and 3 meters off the seafloor. These tripods were initially deployed with 87 m between them near the U.S. Geological Survey/University of Maine tripod. After a period of one week, one tripod was moved to reduce separation to 17 m. Received power levels, bit error rate statistics, and raw data "snapshots" were collect at night for the link 3 m off the seafloor for a period of three weeks. The optical receiver located 1 m off the seafloor was damaged during or soon after deployment. Two attempts to replace the faulty receiver were made but were unsuccessful due to poor weather and connectivity issues with MVCO.

At the ASIT, an upward-looking optical system equipped with a 470 nm transmissometer was deployed on a beam located 4 m below the surface. A downward-looking system was located on the air side of the tower at a height of 12 m above the surface. Received power levels, bit error statistics, and "raw data" snapshots were collected for one month.

RESULTS

The original deployment of the 12m Node optical telemetry system on 17 September 2011 did not yield measurements. This deployment resulted in an 87 m separation between the emitter and

receiver, with questionable alignment. On 21 September the 12 m tripods were repositioned to achieve 17 m separation and good alignment. Optical data link rates of 1, 5 and 10 Mbps were cycled every night from 2000 to 0600 EST through 22 September. As Figure 3 shows for the 12m Node and Figure 2 shows for the ASIT optical modem, optical power levels tracked well across the three data rates showing a near-exact match for measured DC optical power. The AC optical power, however, scales with data rate since the power measurement has a 3 dB point near 5 MHz (the dominant frequency component for 10 Mbps on-off keying). Since all three data rates were supported at all times, on 23 September the experiment was altered: only 5 Mbps data rates were used, and the emitter average power was varied from 150 mW to 3 W. This change to a single data rate allowed not only more continuity across optical power measurements for the rest of the experiment but also the addition of source level as a variable.

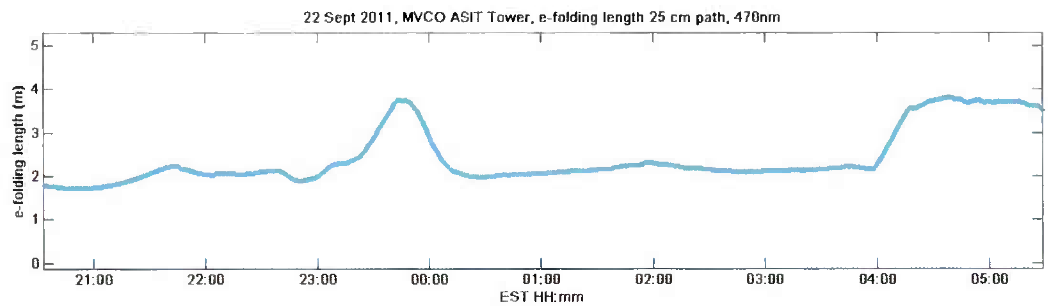

Figure 1. Measured optical attenuation length, ASIT.

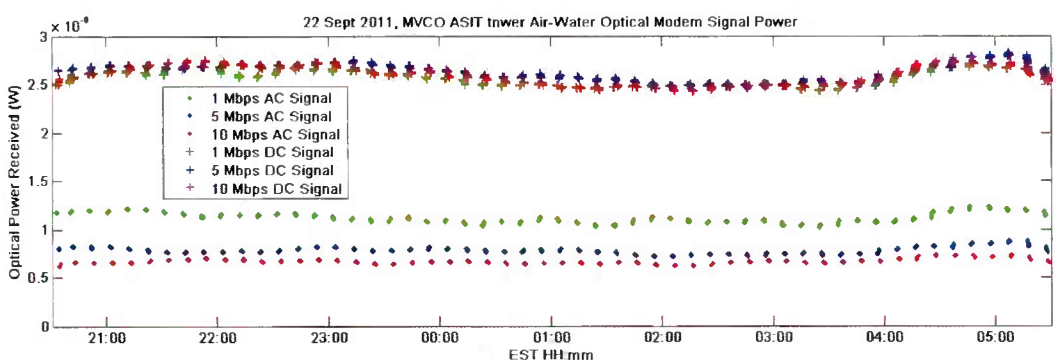

Figure 2. Measured optical power, ASIT.

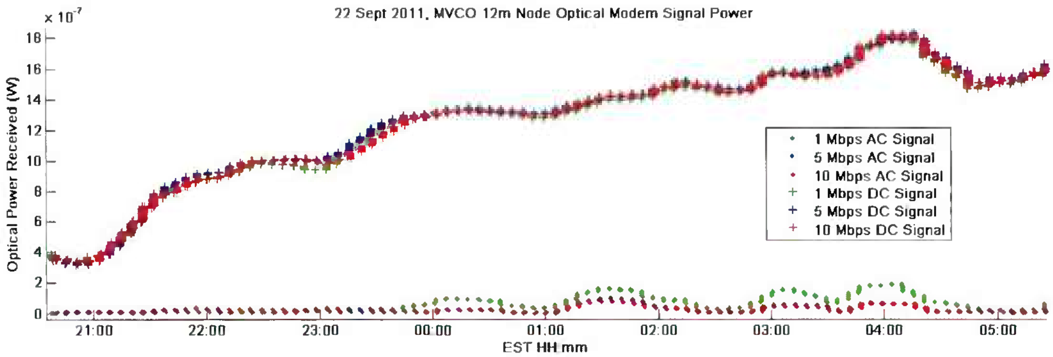

Figure 3. Measured power, 12m Node.

Summary data for 22 September are shown in Figures 1-3. The attenuation length (Figure 1) had spatial and temporal variability, which is evidenced by the differing optical power level trends seen at the ASIT (Figure 2) and 12m Node (Figure 3) during the night. Overall, both systems exhibited positive trends in transmitted optical power as the night progressed, complimented by an increase in measured attenuation length. A snapshot of the synchronization period of our optical signal is shown in Figure 4. The data exhibit no perceptible inter-symbol interference at the rates tested, and signal-to-noise ratio is high.

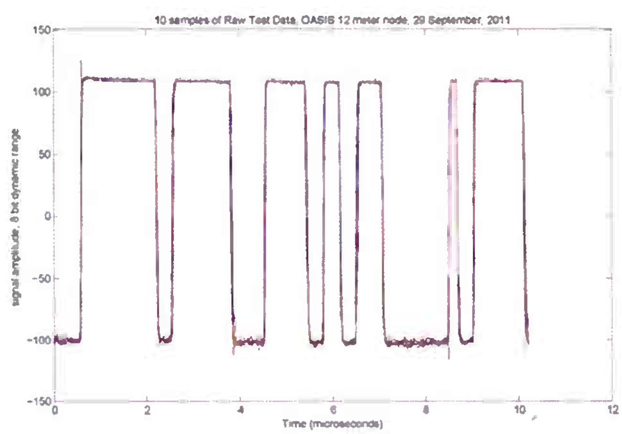

Figure 4. Raw optical data from 12m Node, MVCO.

Early in the experiment, some of the emitter channels suffered a hardware failure such that the emitters in question remained constantly on. This is apparent in the measured AC and DC optical power, as shown in Figure 5, a portion of 25 September. Where DC power is at a maximum, AC power is at a minimum (i.e., 23:28). This hardware failure was subsequently diagnosed and mitigated. At each of the points in Figure 5 the optical link was operating without errors.

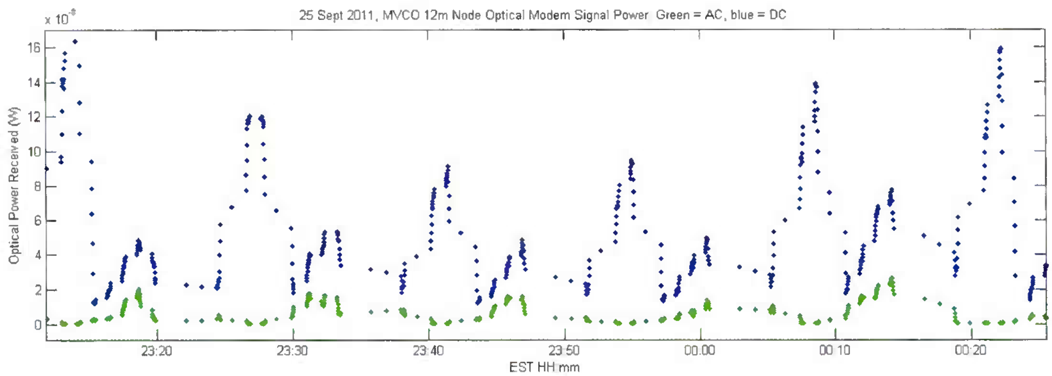

Figure 5. Measured optical power levels with malfunctioning emitters.

IMPACT/APPLICATIONS

The performance of optical communications in highly varying turbid environments will enhance understanding of the viability of optical communications in such environments. This is important for developing performance models for optical communications.

RELATED PROJECTS

The WHOI optical communications group is also funded by the National Science Foundation.

PUBLICATIONS

Farr, N., A. Bowen, M. Tivey, J. Ware, C. Pontbriand (2010). An integrated, underwater optical/acoustic communications system. MTS/IEEE Oceans Conference, Sydney, Australia.

Farr, N., M. Tivey, J. Ware, C. Pontbriand (2010) Optical communication system expands CORK seafloor observatory's bandwidth. MTS/IEEE Oceans Conference, Seattle, WA.

Farr, N., M. Tivey, J. Ware, C.T. Pontbriand, and D.E. Frye (2010) Integrated optical/acoustic communications system for deep sea data transfer and vehicle control. Eos Trans. AGU 91(26), Ocean Sci. Meet. Suppl., Abstract MT23A-05.